levels to derive criteria protective of at least 95% of the species likely to be present. The methodology identifies the following three main components of the criteria:

- Criterion Minimum Concentration (CMC). An estimate of the lowest concentration of DO in ambient water to which an aquatic community can be exposed briefly without resulting in an unacceptable adverse effect. This is the acute criterion.
- Criterion Continuous Concentration (CCC). An estimate of the lowest concentration of DO in ambient water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable adverse effect. This is the chronic criterion.
- Final Recruitment Curve (FRC). A function that defines the maximum allowable exposure duration at DO concentrations between the CMC and CCC necessary to prevent unacceptable reductions in seasonal larval recruitment for sensitive species. Duration of exposure must be reduced when DO concentrations decrease.

The juvenile/adult survival and growth criteria provide useful screening boundaries within which to judge the DO status of a given water body. If DO conditions are above the chronic growth criterion (CCC), then this water body would meet objectives for protection. If DO conditions are below the juvenile/adult survival criterion (CMC), then the water body would not meet the objectives for protection. When the DO conditions are between these two thresholds, then the site would require evaluation of the duration and intensity of hypoxia to determine the suitability of habitat for the larval recruitment objective, if appropriate.

### 4.2.3 Calculation of Acute and Chronic Thresholds for Indicator Species in Suisun Marsh

The site-specific acute and chronic DO values for Suisun Marsh were first calculated by Bailey et al. (2014) using the biological approach recommended for the Virginian Province, but with fish and invertebrate species characteristic of Suisun Bay and Suisun Marsh waters. The species list was further refined with the recommendations of the Expert Panel to focus on the species ecologically important to Suisun Marsh, both introduced and native, while species rarely encountered in the marsh were removed from considerations (Tetra Tech 2017; Table 4-1). Fish and invertebrate species representative of Suisun Marsh were then evaluated using currently available data on sensitivity to low levels of DO (i.e. hypoxia). Threatened and endangered species were also considered in the analysis, including steelhead, chinook and coho salmon, green sturgeon, and Delta smelt. It was determined that sufficient data were available for either locally-occurring species as well as for genus and family-level surrogates of local species to calculate the acute (CMC) and chronic (CCC) values for DO using the U.S. EPA procedures for deriving water quality criteria.

**Table 4-1**
**Refined list of species to calculate DO objectives for Suisun Marsh**

| Species | Baily et al. 2014 List | Refined Species List (Tetra Tech 2017) |
|---|---|---|
| Threespine stickleback (*Gasterosteus aculeatus)* | X | X |
| Striped bass (*Morone saxatilis)* | X | X |
| American shad (*Alosa sapidissima)* | X | X |
| Starry flounder (*Platichthys stellatus)* | X | X |
| Mississippi silversides (*Menidia audens)* | X | X |
| White sturgeon (*Acipenser transmontanus)* | X | X |
| Sacramento splittail (*Pogonichthys macroelepidotus)* | X | X |
| Longfin smelt (*Spirinchus thaleichtys)* | X | X |
| Tule perch (*Hysterocarpus traski)* | X | X |
| Prickly sculpin (*Cottus asper)* | X | X |
| Staghorn sculpin (*Leptocottus armatus)* | X | X |
| Threadfin shad (*Dorsoma petenense)* | | X |
| Common carp (*Cyprinus carpio)* | | X |
| White catfish (*Ameierus catus)* | | X |
| Yellowfin goby (*Acanthogobius flavimanus)* | | X |
| Siberian prawn (*Exopalaemon modestus)* | | X |
| Oriental shrimp (*Palaemon macrodactylus)* | | X |
| Scud (*Gammarus daiberi)* | | X |
| Opossum shrimp (*Hyperacanthomysis longirostris)* | | X |
| Opossum shrimp (*Neomysis kadiakensis)* | | X |
| Chinook salmon (*Oncorhynchus tshawytscha)* | X | X[1] |
| Rainbow trout/steelhead (*Oncorhynchus mykiss)* | X | X[1] |
| Pacific lamprey (*Entosphenus tridentatus)* | X | |
| Green sturgeon (*Acipenser medirostris)* | X | |
| Delta smelt (*Hypomesus transpacificus)* | X | |
| Longjaw mudsucker (*Gillichthys mirabilis)* | X | |
| Bay pipefish (*Syngnathus leptorhyncus)* | X | |
| California halibut (*Paralichthys californicus)* | X | |
| Northern anchovy (*Engraulis mordax)* | X | |
| Pacific herring (*Clupea pallasi)* | X | |
| Shiner perch (*Cymatogaster aggregate)* | X | |

[1] spatially and temporally restricted

**Projection of Juvenile and Adult Survival (CMC – Acute)**

Based on the fish and invertebrate species identified by the Expert Panel a total of 12 data points that relate the survival of juvenile and adult organisms to low DO were used to re-calculate the acute DO threshold for Suisun Marsh. The data were ranked by species on the basis of sensitivity. The four most sensitive species were used to calculate the final acute value (FAV) and included (from most tolerant to least tolerant): striped bass, Mississippi silversides, American shad, and sturgeon. Based on the four most sensitive genus mean acute values (GMAV), the FAV calculated was 2.67 mg/L. This translated into a CMC value of 3.8 mg/L (Tetra Tech 2017).

#### Projection of Sublethal Effects (CCC – Chronic) Without Salmonids

For chronic effects, data from 7 species were available, with 3 data points for fish and 4 data points for other organisms. The most sensitive species for chronic effects were associated with silversides (4.33 mg/L), mud crab (4.63 mg/L), grass shrimp (4.67 mg/L) and sturgeon (4.77 mg/L). The calculated chronic DO value was 5.0 mg/L.

#### DO Thresholds for Protection of Salmonids

The DO criteria derived for the Virginian Province did not incorporate salmonids because the most sensitive life stages for salmonids are associated with freshwater, not brackish estuarine waters. However, salmonids are ecologically important and often use estuaries as juvenile rearing habitat and migration. Migration and estuarine habitat are beneficial uses of the marsh, so it is appropriate to consider salmonids while deriving the CMC and CCC values for Suisun Marsh, and evaluate the temporal extent to which the proposed DO objectives would be protective of salmonids using the marsh for migration (Table 2-1). Protection of embryonic and larval salmonid stages was not considered, as those life stages are only associated with spawning sites, which are located in upstream freshwater reaches of Sacramento and San Joaquin Rivers. When salmonids are included among the four most sensitive species, the calculated CCCs are 5.1 and 6.4 mg/L, depending on the chosen GMCV value and the length of the exposure period.

Based on the available data and expert opinion, these somewhat higher chronic DO concentrations apply to Montezuma, Denverton and Nurse Sloughs in order to support temporary fish passage and some extended rearing in early spring (January through April; P. Moyle, UC Davis, *pers. comm.*, Figure 4-2). The data analysis of grab samples in Montezuma and other larger sloughs suggests that DO concentrations are generally above 6 mg/L, and the highest DO concentrations are measured during spring (Figure 4-3), therefore salmonids are currently protected.

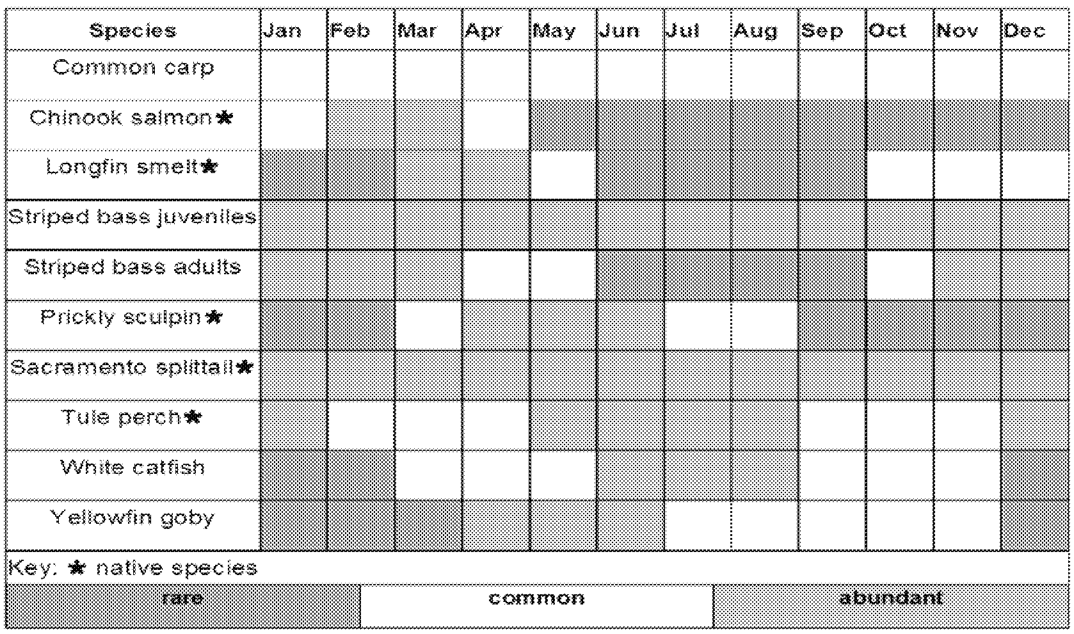
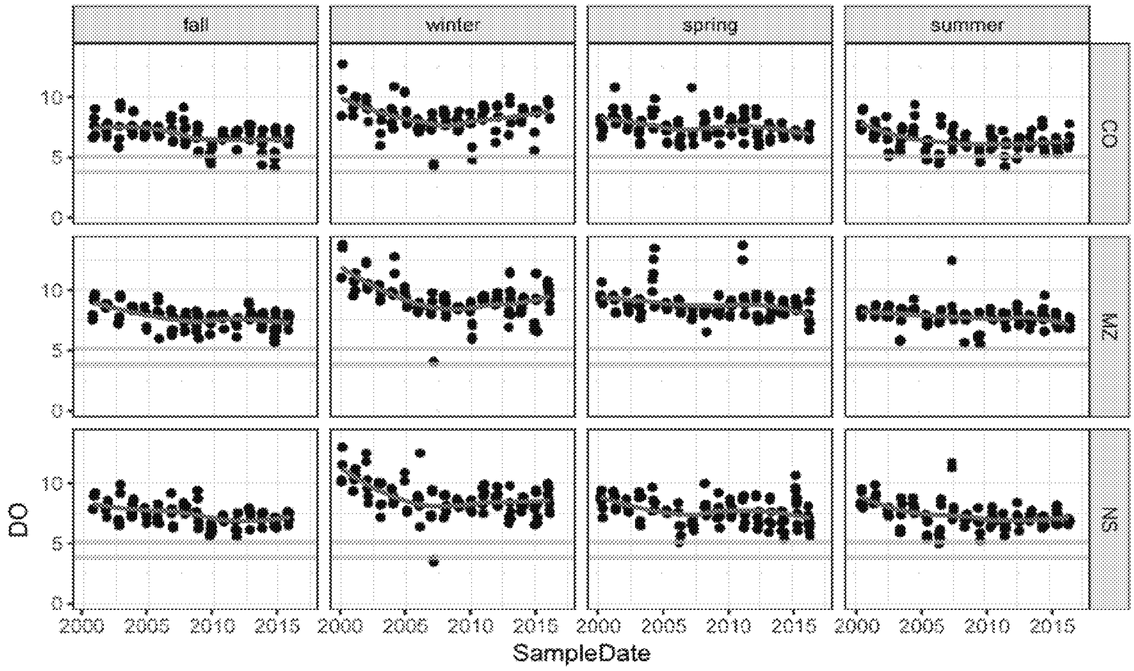



**Figure 4-2 Fish species occurrences in Suisun Marsh by month**

P. Moyle, UC Davis, *pers. comm.*, Tetra Tech (2017)

Figure 4-2 shows qualitatively the most common fish species found throughout the year and indicates that Chinook salmon is frequently found in Montezuma Slough and its major tributaries during January-April, and is especially prevalent in February-March.




Blue line: long-term average DO (mg/L); Tetra Tech (2017)

**Figure 4-3 DO grab sample data in Cutoff (CO), Montezuma (MZ) and Nurse Slough (NS)**

In its 1986 DO criteria for freshwater, U.S. EPA's recommended coldwater criterion, 6.5 mg/L, was expressed as the 30-day mean and reflected findings that DO concentrations below 3 mg/L would result in acute mortality to salmonids, while DO from 5 to 6 mg/L would have a moderate to slight impact on production. The CMC value derived for Suisun Marsh (3.8 mg/L) is higher than the U.S. EPA acute threshold for salmonids (i.e. 3 mg/L) suggesting it is reasonably protective of salmonids' survival. The recalculated CCC value with the salmonid data included in the top four sensitive species resulted in a range of DO from 5.1 to 6.4 mg/L, with the upper limit comparable to the U.S. EPA value of 6.5 mg/L, suggesting that it should be supportive of growth, i.e. offers a reasonable protection against chronic exposure in areas where salmonids might be present in Suisun Marsh. DO concentrations are generally higher in Montezuma, Nurse and Denverton sloughs, where salmonids are found during their outmigration (Figure 4-3), while the back-end sloughs where DO sags are likely to occur, are not generally considered to be suitable salmonid habitats.

### *4.2.4 Larval Recruitment Curve for Striped Bass*

Evidence suggests that fish and other aquatic organisms can tolerate DO concentrations below the calculated CCC threshold for short periods of time and that these short excursions are unlikely to adversely affect larval recruitment in populations of exposed organisms. Based on this evidence, U.S. EPA (2000) developed a generic model to evaluate the cumulative effect of low DO between the CMC and CCC on early life stages, as larvae are more acutely sensitive to low DO than juveniles. The larval recruitment model generates a curve that describes the number of days that larva (or other sensitive life stages) of sensitive organisms can be exposed to DO concentrations below the CCC without negatively affecting the total population. A maximum acceptable reduction in seasonal recruitment due to low DO conditions was conservatively set to five percent. The model developed by U.S. EPA uses laboratory dose-response data along with data that characterizes each genus, their developmental periods, duration of sensitive life stage exposure to low DO conditions, and the proportion of population potentially exposed to a hypoxic event. The four most sensitive genera are then selected to develop the Final Recruitment Curve (FRC). The curve can then be used to evaluate how many days of low DO can be tolerated with no significant effect on recruitment. The number of acceptable days of exposure to low DO decreases as the severity of the low oxygen conditions increases. The Virginian Province FRC was generated with deliberately conservative biological parameters and may be overprotective for other areas (USEPA 2000).

A simplified model for striped bass, the only class of fish specific to Suisun Marsh with extensive DO data, was developed to evaluate the acceptable intensity and duration of low DO across the larval recruitment season (Tetra Tech 2017). Since striped bass is among the four most sensitive species used by U.S. EPA, the recruitment curve for bass in Suisun Marsh closely resembles the FRC for Virginian Province. However, as the Suisun Marsh CMC is higher (3.8 mg/L versus EPA's 2.3 mg/L) the modelled acceptable DO concentrations are more stringent. Given the DO requirements of organisms present in Suisun Marsh and their use of the marsh, the evaluation for striped bass is an appropriate approximation of DO conditions required for protection of important native species including delta smelt and Sacramento splittail (P. Moyle, UC Davis, *pers. comm.*).

### 4.2.5 Proposed DO Objectives and TMDL Targets

The proposed water quality objectives for DO have been developed to protect sensitive aquatic organisms in Suisun Marsh (Table 4-2). The derivation of the objectives followed the U.S. EPA guidelines (Stephen et al. 1985) and the risk-based approach of the Virginian Province saltwater criteria for estuarine and coastal waters,which reflect the DO needs of species present in the waterbody. The Virginian Province approach (USEPA 2000) is considered as the most appropriate to address protection of Suisun Marsh living resource and as a viable technical framework for setting protective DO criteria.

The approach primarily considers species representative of the Virginian Province region. However, comparisons between exposure-response relationships for the mud crab, grass shrimp and the inland silverside for northern and southern populations of each species supports the use and general applicability of the data for other regions. (USEPA 2003-Appendix C). To tailor the approach to Suisun Marsh, we asked the Expert Panel to help identify the sensitive species requirements as the laboratory-based experimental data were not available for many of the Suisun Marsh resident aquatic species. However, surrogate genera or family were commonly available. The selection of appropriate species offers a scientifically defensible approximation of DO tolerances suitable for protecting all aquatic life use. In derivation of the proposed objectives priority was given to the native and non-native ecologically important fish species. The DO requirements of threatened and endangered species were also considered and data for salmonids were included in the derivation of the objectives for specific marsh locations used by salmonids as migratory routes, and as rearing and foraging habitat during active migration. The proposed DO objectives are expressed in mg/L rather than as percent saturation because they reflect the levels of DO from laboratory experiments, which have been directly linked to adverse impacts on the aquatic organism's survival, growth and recruitment. The application of the U.S. EPA's approach in Suisun Marsh represents a comprehensive assessment of the available information, considering tolerance, exposure, and growth/recruitment factors that were appropriately applied to the representative species.

**Table 4-2**
**TMDL DO targets for protection of aquatic life beneficial uses in Suisun Marsh**

| Designated Use | DO concentrations/ Duration | Protection | Time of year |
|---|---|---|---|
| All sloughs and channels | 1-day mean [a] ≥3.8 mg/L (Acute - CMC) | Survival of juvenile and adult fish | Year-round |
| All sloughs and channels | 30-day mean [b] ≥5 mg/L (Chronic – CCC) | Survival/growth of larval/juvenile and adult resident fish; protective of threatened/endangered species | Year-round |
| Montezuma, Nurse and Denverton Sloughs | 30-day mean [b] ≥6.4 mg/L (Chronic – CCC) | Survival and growth of larval/juvenile migratory fish (salmonids); protective of threatened/endangered species | January-April |

[a] estimated as daily average

[b] estimated as 30-day running average

To ensure protection of juvenile and adult resident and migratory fish against unacceptable lethal conditions we recommend DO ≥3.8 mg/L calculated as 1-day mean from continuous data. This value also protects the survival of sturgeon as laboratory data for the sensitive shortnose sturgeon suggest that it can withstand short-term exposures to low DO from 2.3 to 3.1 mg/L (Campbell and Goodman 2004). Our 1-day objective is also more stringent than the U.S. EPA value of 2.3 mg/L.

The chronic 30-day mean DO ≥5.0 mg/L will ensure survival, recruitment and growth of aquatic organisms as well as it will protect threatened and endangered species across Suisun Marsh habitats. According to the U.S. EPA methodology, exposures to DO concentrations above this level will not result in any adverse effects on growth as that value was derived by observing growth effects in the most sensitive larval and juvenile life stages. The 30-day averaging period is consistent with, and fully protects against the effects on larval recruitment greater than five percent.

The striped bass recruitment curve calculated for the conditions in Suisun Marsh indicates that DO above 4.3 mg/L for 30 days will protect against losses in larval recruitment.

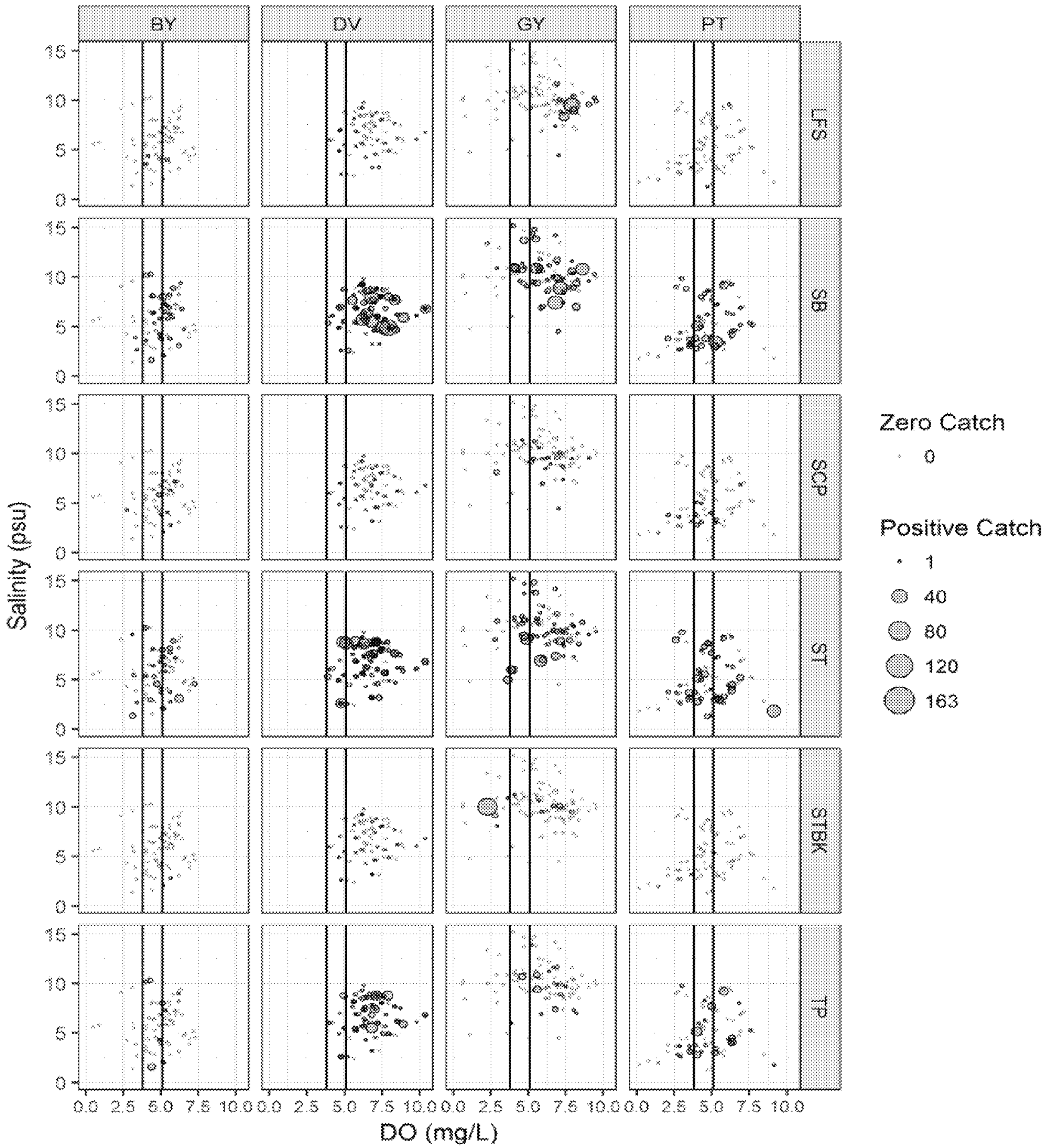
The 30-day mean DO $\geq$6.4 mg/L will apply from January through April in Montezuma, Nurse and Denverton Sloughs to protect listed juvenile salmonids (steelhead, Chinook). Data from the UC Davis long-term fish study tracking fish abundance and DO concentrations (O'Rear and Moyle, 2015) were evaluated to assess the spatial and temporal changes in fish presence and their use of the marsh. This study helps identify types of fish present in different habitats and sloughs throughout the year, and especially when low DO conditions are likely to occur.

In addition, the National Marine Fisheries Service (NMFS) in its biological opinion issued for the 30-year Suisun Marsh Habitat Management, Preservation, and Restoration Plan (SMP) examined the effects of the SMP on the listed and endangered species (Chinook salmon, steelhead and green sturgeon) as the only species potentially sensitive to low DO (NMFS 2013). In summary the NMFS findings included the following:

- Adults and juvenile salmonids and green sturgeon use Montezuma Slough as a secondary migratory pathway as they move downstream through the Delta and Suisun Bay to the Pacific Ocean.
- Listed juvenile salmonids use the tidal sloughs seasonally as a rearing habitat, which they enter at smolt stage, and are expected to be actively emigrating. In particular, Chinook salmon smolts may utilize major tributaries of their migratory route (Montezuma Slough), such as Nurse or Denverton Slough.
- Adult or smolt life stages of Chinook salmon and steelhead are unlikely to be found in the back-end sloughs in the west part of the marsh because these areas are beyond the migratory routes of these species.
- Additionally, the peak emigration of steelhead smolts usually occurs between March and early May, and the upstream migration of adult steelhead occurs from January through April, which coincides with high flow events. Therefore, the timing of migration combined with the low probability of fish entering the small back-end sloughs make it unlikely that steelhead will experience low DO conditions.
- Similarly, the migratory routes for green sturgeon make it unlikely for this fish to frequent the sloughs in the west part of the marsh. Green sturgeon are considered as generally tolerant of DO levels ranging from 2 to 5 mg/L.

Considering the NMFS's assessment of the effects of operation and maintenance of managed wetlands on listed and endangered species, we conclude that the proposed DO objectives are protective of all sensitive species and beneficial uses in Suisun Marsh. This conclusion is supported by the long-term observations of fish presence in different parts of the marsh and their use of the sloughs under different DO regimes (Figure 4-4).

The objectives are attained when average daily, and average monthly DO concentrations are at or above the proposed limits of 3.8 and 5.0 mg/L, respectively. Continuous data collected at regular intervals (every 15 to 60-minutes) are needed to fully evaluate whether the objectives are met. A daily average is the arithmetic average of all DO measurements collected within a 24-hour period. The 30-day (monthly) running average is the arithmetic average of daily averages for any 30 consecutive days. Each subsequent 30-day average is computed by sliding the averaging window by one day.




Proposed DO objectives (3.8 mg/L and 5.0 mg/L - dark vertical lines). Tetra Tech (2017) based on 2000-2015 fish data collected and compiled as part of the UC Davis Fish Study (O'Rear and Moyle, 2015)

Sloughs: BY - Boynton; DV - Denverton; GY - Goodyear; PT - Peytonia

Fish species: LFS - longfin smelt; SB - striped bass; SCP - prickly sculpin; ST - splittail; STBK - threespine stickleback; and TP - tule perch

**Figure 4-4 DO and salinity conditions and fish abundance during October-November**

## 4.3. Expert Panel Recommendations

The scientific advisory provided valuable insight and context for criteria setting, monitoring requirements, and allowable frequency of non-compliance. The panel also fully supports the derived thresholds for acute and chronic DO objectives proposed for Suisun Marsh sloughs (Table 4-2) and the use of the Virginian Province approach in deriving the objectives. The explanation of the findings and additional suggestions are detailed in the panel's summary of findings (Appendix D).

# 5. NUMERIC TARGETS: MERCURY

The statewide mercury water quality objectives approved by the State Water Board on May 2, 2017, apply to Suisun Marsh (Table 5-1). These objectives reflect the current scientific understanding of how mercury impairs humans, wildlife, and aquatic life by bioaccumulating in animal tissue. The mercury targets adopted by the Bay Mercury TMDL were established using the same assumptions and are equally protective of both human health and wildlife when compared to the statewide objectives. For example, the statewide objective for sport fish of 0.2 mg/kg in trophic level 3 or 4 fish is equal to the protection of human health target in the Bay Mercury TMDL. In addition, the statewide prey fish objective for the California Least Tern of 0.03 mg/kg similarly matches the target for protection of aquatic organisms and wildlife in the Bay Mercury TMDL. The statewide mercury objectives in Table 5-1 include two possible objectives for prey fish; the Least Tern limit is more stringent than the general prey fish limit. The Bay Mercury TMDL includes the more stringent prey fish limit, which is protective of both objectives. Therefore, when the Bay Mercury TMDL targets are met, the waterbody will also be meeting the applicable water quality objectives.

**Table 5-1**
**Water quality objectives currently applicable in Suisun Marsh**

| Purpose | Limit | Description |
|---|---|---|
| Sport Fish Water Quality Objective | 0.2 mg/kg wet weight in skinless fillet | Average mercury concentration measured in trophic level three (15-50 cm) or trophic level four fish (20-50 cm), whichever is the highest, measured in a calendar year |
| Prey Fish Water Quality Objective- | 0.05 mg/kg wet weight in whole fish | Average mercury concentration measured in whole fish, 5–15 cm in length, measured in a calendar year |
| California Least Tern Prey Fish Water Quality Objective | 0.03 mg/kg wet weight in whole fish | Average mercury concentration measured in whole fish, < 5 cm in length, measured April 1 to August 31 |

## 5.1. APPLICABILITY OF THE BAY TARGETS TO SUISUN MARSH

### *5.1.1 Derivation of the Bay Mercury Objectives*

The water quality objectives and associated numeric targets adopted by the Bay Mercury TMDL reflect the primary concerns related to the presence of mercury in aquatic ecosystems, i.e., account for risks to human health from consumption of fish and protect aquatic life and wildlife that consume fish. Therefore, these objectives provide a basis to establish safe levels of mercury for Suisun Marsh.

The derivation of the fish target to protect people who consume Bay fish follows the U.S. EPA methodology to establish the national criterion for methylmercury in fish tissue (USEPA 2001) and is more stringent than the national human health criterion of 0.3 mg/kg in fish. The Bay fish target assums that people eat Bay fish more frequently and is based on the locally derived fish consumption rate of 32 g/day (CDHS&SFEI 2000). The U.S. EPA's reference dose of 0.1 µg MeHg per kg body weight per day is then applied to determine the safe mercury concentrations in fish tissue. The target to protect human health is 0.2 mg/kg average wet weight concentration measured as total mercury in five most commonly consumed Bay fish. The detailed assumptions used in derivation of the targets are discussed in the Bay TMDL Staff Report (SFBRWQCB 2006).

Compliance with the human health fish target is determined using the average mercury concentration in the edible portions of a mix of five commonly-consumed fish species (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker). These five species are all carnivores in trophic levels 3 (meaning the prey species are herbivores) or 4 (meaning the prey species are carnivores) and accordingly would be expected to have bioaccumulated proportionally more mercury than species in lower trophic levels. The halibut, striped bass and white sturgeon are analyzed as muscle tissue without skin, while the white croaker is analyzed with skin, and the jacksmelt with skin and skeleton because people usually eat jacksmelt whole.

The fish target to protect fish consuming birds and wildlife was set to 0.03 mg of mercury per kg measured in small whole fish 3–5 cm in length. This fish target reflects consumption of fish less than 5 cm in length (e.g., topsmelt, jacksmelt, and northern anchovy) by California least tern based on the methodology developed by the USFWS (2003), which was also used in other TMDLs. Predatory birds with diets which depend entirely on Bay fish and aquatic organisms, have been identified as the most sensitive mercury receptors (Davis et al. 2003, Melwani et al. 2012). Therefore, the objective calculated to protect birds is also expected to protect other wildlife reliant on the Bay for food. In addition, the prey fish target coincides with the mercury thresholds considered as protective of the threatened California least tern, which, due to its status, ensures protection of rare and endangered species (USFWS 2003).

### *5.1.2 Rationale for Suisun Marsh Hg Targets*

Sources of mercury in Suisun Marsh, located at the northeastern end of the Bay and western end of the Delta, are similar to those identified in all segments of the San Francisco estuary, and include historic mining activities, atmospheric deposition, refinery and municipal waste and urban stormwater runoff. Applying the same targets to Suisun Marsh allows for coordination of implementation actions and time schedules already in place as a result of the Bay Mercury TMDL, and is consistent with the 2017 statewide water quality standards for mercury, which also set fish tissue targets instead of sediment or water column concentrations.

The San Francisco Bay and Tomales Bay TMDLs set fish tissue targets and require direct monitoring of appropriate trophic levels and sizes of fish to evaluate compliance with the targets to protect human health and wildlife. A similar approach is appropriate for the Suisun Marsh for the following reasons:

1. Mercury in fish tissue is assumed to be composed entirely of toxic MeHg, which makes fish tissue targets more conservative and protective than water column targets.
2. Measurement of mercury in fish muscle tissue is a direct method for determining compliance with the fish target, rather than introducing uncertainty from the linkage analysis between water and fish mercury concentrations.

3. The laboratory analytical methods for total mercury in fish tissue have a lower detection limit than those for aqueous methylmercury in water.
4. The approach is consistent with the Bay Mercury TMDL and its Implementation Plan. Suisun Marsh is hydrologically connected to Suisun Bay and to San Francisco Bay.
5. The Watershed Mercury Permit (R2-2017-0041) and the Municipal Regional Permit (R2-2015-0049) already implement waste load and load allocations required by the Bay Mercury TMDL, including municipal waste and stormwater from areas adjacent to the Suisun Marsh area.

Following these recommendations, and as adopted in the Bay Mercury TMDL, the Basin Plan's 4-day average marine water quality objective (0.025 µg/L) is outdated and should be replaced in Suisun Marsh . As described in the Bay TMDL (SFBRWQCB 2006), the Basin Plan's 4-day mercury objective is based on science over three decades old (USEPA 1985). Furthermore, the Basin Plan objective reflects studies on the Eastern oyster, a low trophic level species that is not present in Suisun Marsh or San Francisco Bay.

The suspended sediment target for mercury developed for the Bay Mercury TMDL and the Tomales Bay Mercury TMDL is not considered relevant for Suisun Marsh. In San Francisco and Tomales Bays, resuspension of sediments was identified as a significant internal source of mercury, and a sediment target specifies an approach to control the overall mercury supply. In Suisun Marsh, however, resuspension of local bed sediment is a smaller source relative to contributions from upstream watersheds and tidal action Moreover, the primary concern in the marsh is methylation of inorganic mercury in wetland and slough environments, where suspended sediment mercury concentrations are not as indicative of methylation potential as other factors, such as dissolved oxygen levels. The Delta TMDL notes that over 80 percent of the total mercury input to the Delta is contributed by the Sacramento River and Yolo Bypass watersheds, and these sources are separately targeted by the load reduction actions in existing TMDLs. The newly adopted, 2017 statewide mercury standards do not include sediment concentrations, which confirms that the level of mercury in fish tissue provides a primary means to protect people and wildlife from consuming fish, which contain high levels of mercury.

## 5.2. Protection of Human Health and Wildlife in Suisun Marsh

### *5.2.1 Protection of Human Health*

Suisun Marsh wetlands, channels, and sloughs are popular fishing destinations and the fish consumption rate (32 g/day) of people fishing in the sloughs and the overall mix of species they consume is expected to be similar to that in the Delta and San Francisco Bay area. Indeed, the local population in the Fairfield-Suisun area may fish not only in Suisun Marsh but also in San Francisco Bay and the Delta. This fish consumption rate was used in both the Bay and Delta TMDLs and represents a consumption rate protective of 95 percent of the people who chose to eat San Francisco Bay fish on a regular basis. Selection of the higher consumption rate than the U.S EPA general population rate of 17.5 g/d (protective of 90% of population) makes the calculated target more protective of people likely to consume local fish.

The fish species and sizes used in evaluation of compliance with the targets may differ slightly but generally include a mix of commonly-consumed TL3 and TL4 fish. Each of the previously mentioned TMDLs has site-specific fish identified to comply with the targets that reflect locally available species and consumption preferences.

Fish populations in Suisun Marsh have been sampled by UC Davis for over 20 years and showed more than 50 fish species present (O'Rear and Moyle, 2015). This sampling characterized the abundance of fish species, but not tissue mercury concentrations. Fish that may be consumed by people include striped bass, black bullhead, white catfish, white croaker, and common carp. White catfish is a high trophic level (TL4), bottom feeding fish that is relatively abundant in Suisun Marsh and the Delta. This is a desirable and popular fish species because of its abundance, accessibility and size. The white catfish grows at a slow rate, which also makes this fish susceptible to mercury accumulation (Davis et al. 2000a). Largemouth bass, although common in the Delta, were caught only rarely in Suisun Marsh. Adult striped bass are not common but juvenile striped bass use the wetlands and smaller channels as a nursery (Crain and Moyle, 2011). Overall, more than 99,000 striped bass were caught during the study period to date. Since juvenile striped bass are the most frequent fish caught in the otter and midwater trawls in the sloughs and in beach seines, and bass is one of the most commonly consumed sport fish, it is a good indicator to evaluate protection of human health in Suisun Marsh and elsewhere.

We propose that the human health target of 0.2 mg/kg be measured in striped bass, the most abundant fish in Suisun Marsh. The mercury level should be expressed as an average wet weight concentration of total mercury in skinless fillets. The striped bass is already a target indicator species to evaluate human health sampled in San Francisco Bay and the target is consistent with the statewide sport fish objective of 0.2 mg/kg for waters with the Commercial and Sport Fishing use, such as Suisun Marsh sloughs.

### 5.2.2 Protection of Wildlife

The fish target to protect wildlife in the Delta and Bay TMDLs is 0.03 mg/kg, and may be used without modification for Suisun Marsh. A variety of small fish were found in the sloughs from 1979 through 2014 (O'Rear and Moyle, 2015), however, mercury was measured in Mississippi silversides only. This relatively small fish (average lengths of 4.4 to 7.9 cm) is considered an important indicator of wildlife exposure to MeHg in the Bay because silversides forage in shoreline marshes and shallow water habitats, which exhibit greater potential for Hg methylation (Melwani et al. 2012). The Bay TMDL used 3–5 cm fish for the fish target to protect wildlife, since the California least tern eats fish less than 5 cm. The least tern is a very sensitive species that is on the federal list of endangered species. Acordingly, this target is also the most stringent of the three statewide mercury objectives established to protect aquatic life and aquatic-dependent wildlife and is protective of all federally- and state-listed endangered species. California least terns are not common in Suisun Marsh, they have been known to breed at one location on the east side of the marsh and to forage in the bays, sloughs, tidal wetlands, and managed wetlands (USBR 2011).

Other piscivorous birds found in the marsh that feed predominantly on aquatic prey are double-crested cormorant and belted kingfisher. Since they can eat somewhat larger fish (the belted kingfisher's diet is typically <10.5 cm, and the double-crested cormorant's diet is 5–15 cm) the proposed target is protective of all piscivorous bird species, because it has been established to protect the most-sensitive species (California least tern) in the season of greatest sensitivity to mercury, which is the breeding season.

## 5.3. SUMMARY OF RECOMMENDATIONS

The numeric targets, which currently apply in all San Francisco Bay segments should be extended to Suisun Marsh. These include the targets for the protection of humans, aquatic organisms and piscivorous wildlife: 0.2 mg/kg (wet weight) in muscle tissue of large trophic level (TL3 or TL4) fish such as striped bass; 0.03 mg/kg (wet weight) in whole small fish (~ 50 mm in length) such as Mississippi silverside; and the existing 1-hour acute water quality objective of 2.1 µg/L.

The target for large trophic level fish is protective of humans eating 32 g/day uncooked fish per week of commonly consumed, large fish and all wildlife species that consume large fish. The small fish target is protective of birds that consume small fish. The Basin Plan 1-hour average total mercury objective of 2.1 µg/L protects against acute effects to aquatic life.

The proposed targets are shown in Table 5-2. It is implicit in this target selection that water quality objectives are met when fish mercury levels are met and the mercury concentrations in the water column do not exceed 2.1 µg/L.

These are the same targets that were adopted in other Bay-area TMDLs (e.g., San Francisco Bay, Guadalupe River, and most recently in Tomales Bay).

**Table 5-2**
**Numeric targets for San Francisco Bay and Suisun Marsh**

| Purpose of Target | Target | Target Description |
|---|---|---|
| Protection of human health | 0.2 mg/kg ww in fish tissue | Average mercury concentration measured in edible portion of TL3 and TL4 fish* |
| Protection of aquatic organisms and wildlife | 0.03 mg/kg ww in fish | Average mercury concentration measured in whole fish, 3–5 cm in length |

*Commonly consumed fish present in the sloughs and channels of Suisun Marsh such as striped bass and white catfish (TL4)

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# 6. SOURCE ANALYSIS: ORGANIC ENRICHMENT, DISSOLVED OXYGEN, AND NUTRIENTS

Sources contributing substances, which could potentially lower DO concentrations in Suisun Marsh sloughs were assessed for the presence of total organic carbon (TOC), biological oxygen demand (BOD) and nutrients. The relationships between these substances and low DO are explained in more detail below.

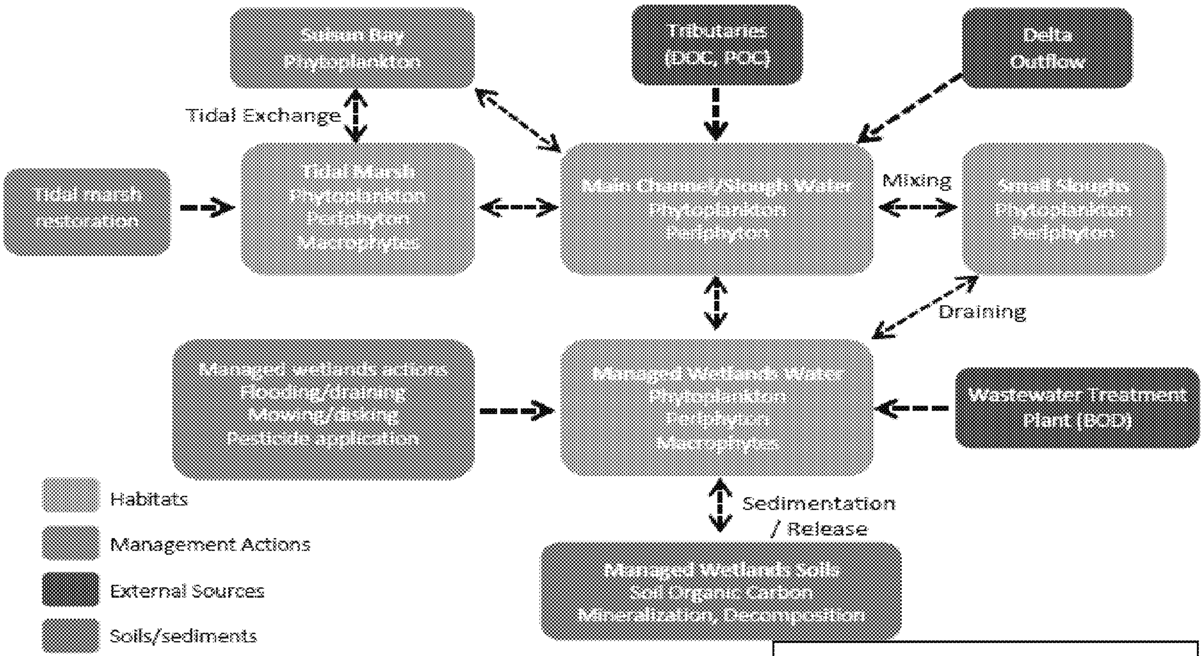
## 6.1. ORGANIC CARBON AND LOW DO

Because oxygen is used in decomposition of organic matter the availability, amount and type of organic material present in the sloughs and the surrounding areas could have a significant impact on lowering levels of DO. The high organic carbon concentrations in Suisun Marsh have been attributed to high levels of primary production in the interior of the marsh (Enright et al. 2009). These include primary production of macrophytes in shallow waters, attached algae in shallow calm areas such as tidal creeks, and phytoplankton production in deeper, clearer areas with intermediate residence times (e.g., small sloughs). Moreover, long water residence times, nutrient availability, and relative absence of alien clams also intensify primary production in the interior of Suisun Marsh (DFG 2008).

However, in addition to this natural, internal production, organic carbon can reach Suisun Marsh in several other natural and anthropogenic ways, including:1) tidal exchange with the Bay; 2) runoff from the surrounding watersheds; 3) wastewater treatment plant discharge; 4) managed wetland discharge; and 5) exchange with tidal marshes. Detritus from emergent tidal vegetation can also be a source of substantial amounts of organic matter in estuaries and coastal oceans (Raymond and Bauer, 2001). Adjacent uplands that remain hydrologically connected to the marsh also contribute vegetation detritus, as well as agricultural and stormwater runoff. The managed wetlands in Suisun Marsh can discharge significant amounts of organic matter as a result of soil and vegetation management activities at these sites. Finally, suspended sedimentary material containing plant material can be tidally transported from the adjacent Grizzly and Suisun Bays.

Factors such as location, primary production type, hydrology, and weather determine the sources and distribution of organic carbon. (Mueller-Solger and Bergamaschi, 2005). For instance, while tidal and managed wetland areas support vascular plant production, phytoplankton production occurs in open water areas and shallow, stagnant areas support benthic and epibenthic algal and submerged aquatic vegetation. The hydrologic connectivity of these habitats determines the dominant organic carbon sources to a particular area of the marsh. A conceptual model of sources and distribution of organic carbon is shown in Figure 6-1. A summary of BOD organic carbon loads from different sources is shown in Table 6-1.

The interactions between types of organic material present in the marsh and sloughs and DO are complex and highly variable. Downing et al. (2010) used the fluorescence index (FI) to evaluate the relative contribution of algal versus terrestrial dissolved organic matter (DOM). Algal derived materials have lower aromatic content, lower molecular weight, and higher FI compared to the more-degraded DOM from dead plants and soils of terrestrial origin. FI values in Wetland 112 and 123 ranged between 1.2 and 2, which indicates a mixture of DOM from different sources. Some increases in FI observed in Wetland 123 long after the wetland flooding might suggest that DOM was generated from algal production and leaching from vegetation in the wetland and the observed changes in DOM composition could be due to primary production within the wetland or inflow and water exchange with the adjacent slough.




*Modified from Tetra Tech (2013a)*

**Figure 6-1 Conceptual model of sources and distribution of organic carbon in Suisun Marsh**

**Table 6-1**
**Summary of BOD and organic carbon loads from different sources**

| Source | BOD Loads (kg/day) | DOC Loads (kg/day) | Reference |
|---|---|---|---|
| Surrounding watersheds (stormwater) | 3776 | 1416 | Davis et al. (2000b) |
| FSSD treated wastewater effluent | <100 | 40 | NPDES Permit No. CA0038024 |
| Managed wetland discharges | | 1,981–8,958 during drain events | Bachand et al. 2010 |

## 6.2. Sources and Loads of Organic Carbon

### *6.2.1 Surrounding Watersheds*

Runoff from surrounding watersheds, which contains both vegetation debris and phytoplankton, is a major external source of organic carbon to the marsh. Several creeks enter Suisun Marsh, including Valley Creek, Suisun Creek, Ledgewood Creek, Laurel Creek, Union Creek, and Denverton Creek (Figure 8-1). The creeks drain watersheds with a mix of low intensity agricultural, urban, and open space land uses. The tributary inputs of organic carbon and BOD can be estimated based on a previous study by Davis et al. (2000b). The Fairfield sub-watersheds were estimated to export a total of 3,776.5 kg/day of BOD or 1,416.2 kg/day of organic carbon at a rate of 15.7 kg/ha/yr BOD or 5.9 kg/ha/yr organic carbon (Tetra Tech 2013a).

BOD and total organic carbon (TOC) concentrations were recently sampled during two storm events and several dry weather dates in the tributaries, including Laurel Creek, Ledgewood Creek, and Suisun Creek. The concentrations of BOD and TOC measured for these sampling events are listed in Table 6-2. These concentrations along with the estimated monthly flow were used to calculate loads of BOD and TOC from tributaries to Suisun Marsh. Estimated loads of BOD based on the measured concentrations ranged from 5.7 kg/ha/yr in Suisun Creek to 13.8 kg/ha/yr in Laurel Creek; estimated loads of TOC ranged from 4.1 kg/ha/yr in Suisun Creek to 16.4 kg/ha/yr in Laurel Creek. These estimated rates of export are similar to the previous estimates by Davis et al. (2000b).

**Table 6-2**
**Concentrations of BOD, and TOC in Suisun Marsh creeks sampled during 2013, and estimated loads**

| Constituents | Date | Laurel Creek upstream | Laurel Creek downstream | Ledgewood Creek upstream | Ledgewood Creek downstream | Suisun Creek upstream | Suisun Creek downstream |
|---|---|---|---|---|---|---|---|
| BOD (mg/L) | 2/19/2013 | 8.78 | 4.46 | 7.73 | 6.56 | 4.27 | 3.16 |
| | 9/18/2013 | ND | ND | ND | ND | ND | ND |
| | 10/11/2013 | 5.84 | 4.82 | 2.54 | 6.5 | 5.96 | 4.28 |
| | 10/28/2013 | ND | ND | ND | ND | ND | ND |
| | 11/1/2013 | 6.18 | 2.7 | ND | 6.72 | ND | ND |
| | 12/10/2013 | 5.08 | 4.65 | 4.69 | 5.09 | 5.6 | 5.48 |
| Total organic carbon (TOC, mg/L) | 2/19/2013 | 10.1 | 7.66 | 8.73 | 6.18 | 2.47 | 2.33 |
| | 9/18/2013 | 3.11 | 3.07 | 8.78 | 8.69 | 3.6 | 2.83 |
| | 10/11/2013 | 3.13 | 3.01 | 3.59 | 3.7 | 2.4 | 2.4 |
| | 10/28/2013 | 2.58 | 2.6 | 5.3 | 5.67 | 2.5 | 1.97 |
| | 11/1/2013 | 13.1 | 7.6 | 6.6 | 8.2 | 5.9 | 7.5 |
| | 12/10/2013 | 3.5 | 2.4 | 3.69 | 3.63 | 3.27 | 3.19 |
| BOD (kg/ha/yr) | | 13.8 | 7.5 | 11.6 | 10.9 | 7.3 | 5.7 |
| TOC (kg/ha/yr) | | 16.4 | 12.3 | 15.0 | 11.7 | 5.3 | 5.2 |

ND – non-detect

### *6.2.2 Wastewater Treatment Plant Effluent*

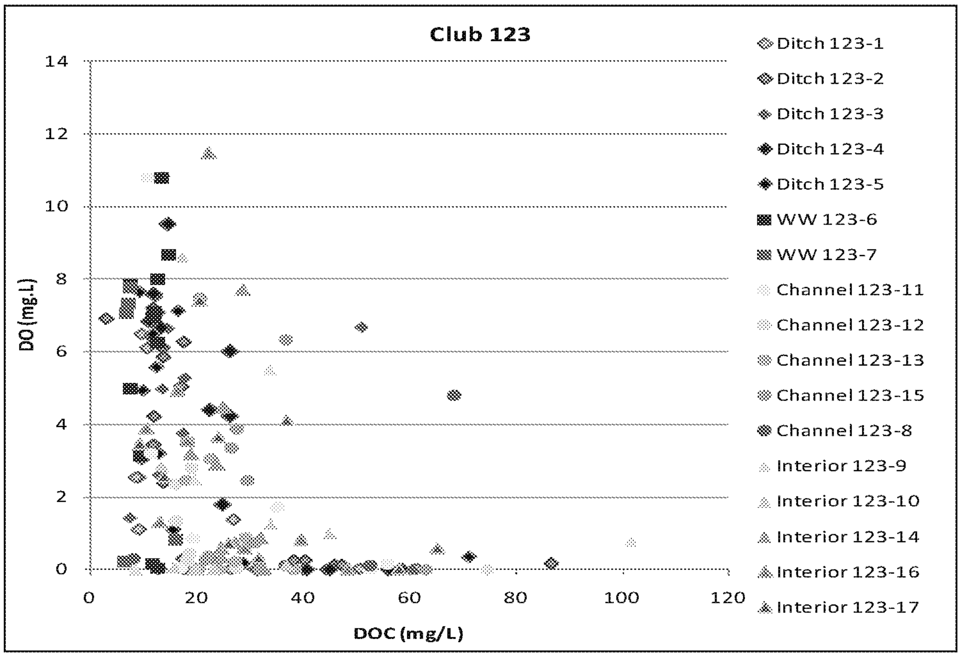
Fairfield Suisun Sewer District (FSSD) discharges a majority of its treated wastewater effluent to Boynton Slough. The plant is an advanced secondary treatment plant. NPDES Permit No. CA0038024 limits the amount of BOD in the effluent to an average monthly concentration of 10 mg/L. The plant presently treats on average up to 16.1 mgd (2000–

2002), with an average dry weather flow of 14.1 mgd. Of the treated effluent, an annual average of 14.4 mgd is discharged to Boynton and Peytonia sloughs in Suisun Marsh, and 1.7 mgd is reclaimed for agricultural irrigation. Although the maximum allowable discharge of BOD load from FSSD was approximately 900 kg/day or 346 kg/day calculated as DOC, actual discharges are usually much lower. For example, in 2012, the average daily BOD load was less than 107 kg/day (calculated DOC load of 40.1 kg/day) (NPDES discharge data).

### *6.2.3 Managed Wetland Discharges*

Organic carbon concentrations and seasonal variability in Suisun Marsh managed wetlands and sloughs are discussed in Tetra Tech (2013a). The role of managed wetlands on dissolved organic carbon (DOC) in tidal sloughs was emphasized in the study of Bachand et al. (2010). Higher DOC concentrations were measured within managed wetlands than the adjacent sloughs. DO was consistently low in water with high DOC concentrations (Figure 6-2) and was typically below 1 mg/L when DOC concentrations exceeded 40 mg/L.

DOC concentrations in the managed wetlands increased within the first few weeks during fall wetland filling up events and then stabilized. Upon release, managed wetlands sent pulses of high DOC water to their adjacent sloughs, resulting in increased DOC concentrations in receiving waters. Based on this analysis, the managed wetlands received 468 mg/m$^2$ (wetland area)/tide/inch during the flood event and discharged 306 and 826 mg/m$^2$ (wetland area)/tide/inch at Wetland 112 and 123 during drainage events. Typically, up to 2 inches of water is imported per flood event, and 4 inches of water per tide event is discharged during drainage events. This suggests a load of DOC of 1,515 kg/day and 2,538 kg/day transported from the sloughs to the managed wetlands during flood events, and 1,981 and 8,958 kg/day transported from the wetlands to the sloughs during drainage events at Wetland 112 and Wetland 123, respectively. These data show that although the DOC concentrations and loads at managed wetlands may vary significantly from year to year, they make net positive contributions to DOC concentrations in adjacent waters.




*From Downing et al. 2010*

**Figure 6-2 DO versus DOC concentrations at managed wetland 123**

### *6.2.4 Tidal Marshes*

Tidal marshes are productive systems that contribute organic matter to the receiving water body naturally. In a study of carbon types and bioavailability in the Delta and Suisun Marsh, tidal marsh sloughs in Suisun Marsh were found to have higher levels of dissolved organic carbon, particulate organic carbon, and phytoplankton-derived carbon than other environments in the Delta (Sobczak et al. 2002). The study suggested that the bioavailable particulate organic carbon, derived primarily from phytoplankton production, including from within the tidal marsh, forms a critical food source for pelagic fish species. Although sloughs fully surrounded by tidal marshes are not very common in Suisun Marsh, Peytonia and Boynton Sloughs both have tidal marshes connected to them. Accordingly, tidal marshes may be a significant source of dissolved organic carbon in these sloughs.

### *6.2.5 Load Summary*

A summary of organic carbon loads from different sources is shown in Table 6-1. The load comparison shows that the managed wetlands are the largest direct source of organic carbon to the sloughs; however, a portion of this load could be attributed to natural processes.

## 6.3. SOURCES OF NUTRIENTS TO SUISUN MARSH

The term “nutrients” refers to nitrogen or phosphorus-containing substances, common sources of which include fertilizers, animal wastes, and both treated and untreated wastewater. However, nutrients can also enter waterways through atmospheric deposition and nitrogen fixation by microbes in the water, and through the decomposition process within wetland soils, which releases nitrogen into the water. Nutrients enter Suisun Marsh through Delta outflow, which receives nutrients from the Sacramento and San Joaquin Rivers, which both drain large urban and agricultural areas; exchange with the nutrient-rich Suisun Bay, tributary inflow that drains urban and agricultural areas, discharge from the FSSD wastewater treatment plant, atmospheric deposition, and internal releases from wetland soils. During rainy winters, stormwater runoff from tributaries may influence water quality in Suisun Marsh more significantly than during the dry season. Table 6-3 shows a summary of nutrient loads from different sources. There are limited data for phosphorus sources. However, given that N to P ratios in the water column of Suisun Marsh, which indicate nitrogen to be the limiting nutrient (Appendix B), nitrogen loads may play a more important role than phosphorus loads.

**Table 6-3**
**Summary of nutrient loads from different sources**

| Sources | N loads (kg/day) | P loads (kg/day) | Reference |
|---|---|---|---|
| Surrounding Watersheds | 112 | 103 | Davis et al. (2000b) |
| FSSD treated wastewater effluent | 1332 (970-1250) | | Load estimated from average N concentrations (seasonal loads) |
| Atmospheric Deposition | Wet: 234 (wetlands), 82 (water surface)<br>Dry: 156 (wetlands), 55 (water surface) | | NADP for areal wet deposition and CASTNET for dry deposition rate; area of wetlands (86,000 acres) and open water (30,000 acres) used to estimate total loads |

Based on the previous San Francisco Bay regional study by Davis et al. (2000b), tributary inputs from the Fairfield sub-watersheds were estimated to be 112 kg N/day and 103 kg P/day, or 0.32 kg N/ha/yr nitrate and 0.18 kg P/ha/yr phosphorus. Those estimated loads were based on modeled runoff and observed stormwater concentrations from each sub-watershed. More recently, nutrient concentrations were directly measured in Laurel Creek, Ledgewood Creek, and Suisun Creek during two storm events and several dry weather sampling events (Table 6-4). The observed nutrient concentrations for these sampling events by speciation are listed in Appendix A. The recently observed concentrations along with the estimated monthly flow were used to calculate updated loads of nutrients from tributaries to Suisun Marsh. Estimated loads from the recent sampling ranged from 1.5 kg N/ha/yr in Suisun Creek to 4.3 kg N/ha/yr in Ledgewood Creek and 0.08 kg P/ha/yr in Suisun Creek to 0.33 kg P/ha/yr in Laurel Creek. These levels are consistent with the previous estimates by Davis et al. (2000b).

The concentrations of nutrients in the FSSD wastewater treatment plant effluent are relatively low. Ammonia concentrations in the plant effluent are typically below 0.1 mg/L, although occasional spikes greater than 0.5 mg/L have also been reported. Based on the average discharge rate in 2011 and the measured average daily maximum concentration of 0.07 mg N/L, the measured ammonia load was approximately 1.75 kg N/day. Organic nitrogen concentrations in FSSD effluent normally vary from 0.05 to 1 mg/L. Nitrite and nitrate concentrations are generally at 12–33 mg/L. The estimated mean TN load from 2012–2013 is 1332 kg N/day, although the daily TN load from FSSD varies seasonally. The higher loads in March during the higher rainfall periods suggest that the higher discharge rates, not elevated nutrient concentrations in the effluent, are responsible for variations in the TN loads.

**Table 6-4**
**Loads and concentrations of total nitrogen and phosphorus in Suisun Marsh creeks sampled during 2013**

| Constituents | Date | Laurel Creek upstream | Laurel Creek downstream | Ledgewood Creek upstream | Ledgewood Creek downstream | Suisun Creek upstream | Suisun Creek downstream |
|---|---|---|---|---|---|---|---|
| Total Nitrogen (mg/L) | 2/19/2013 | 1.72 | 2.163 | 2.23 | 2.83 | 0.692 | 0.671 |
| | 9/18/2013 | 0.473 | 0.242 | 1.05 | 0.819 | 0.329 | 0.375 |
| | 10/11/2013 | 1.11 | 0.57 | 0.83 | 0.88 | 1.248 | 1.248 |
| | 10/28/2013 | 0.505 | 0.447 | 0.96 | 0.959 | 1.59 | 0.971 |
| | 11/1/2013 | | | | | 2.34 | 2.15 |
| | 12/10/2013 | 1.36 | 1.41 | 1.2 | 1.13 | 1.52 | 4.05 |
| Total Phosphorus (mg/L) | 2/19/2013 | 0.094 | 0.075 | 0.094 | 0.071 | 0.021 | 0.009 |
| | 9/18/2013 | 0.106 | 0.327 | 0.608 | 0.386 | 0.438 | 0.054 |
| | 10/11/2013 | 0.05 | 0.047 | 0.156 | 0.158 | 0.054 | 0.047 |
| | 10/28/2013 | 0.026 | 0.038 | 0.408 | 0.271 | 0.141 | 0.054 |
| | 11/1/2013 | | | | | 0.337 | 0.254 |
| | 12/10/2013 | 0.134 | 0.146 | 0.189 | 0.172 | 0.306 | 0.358 |
| Total nitrogen (kg/ha/yr) | | 2.75 | 3.28 | 3.56 | 4.31 | 1.49 | 1.84 |
| Total phosphorus (kg/ha/yr) | | 0.18 | 0.20 | 0.33 | 0.24 | 0.18 | 0.09 |

Atmospheric deposition, which cannot be controlled, contributes a load that may exceed the contribution from the surranding watershades. The nearest station measuring nitrogen deposition as part of the National Atmospheric Deposition Program (NADP) network is located at Davis, CA (station CA88). Total inorganic nitrogen ($NH_4$ + $NO_3$) wet deposition loads measured at this station for the last 10 years (2000–2010) averaged 2.45 kg N/ha/yr. This represents an inorganic nitrogen wet deposition load of 315.5 kg N/day to Suisun Marsh (assuming a wetland area of 86,000 acres and an open water area of 30,000 acres). Dry to wet nitrogen deposition ratios at a nearby station (YOS404) from a Clean Air Status and Trends Network (CASNET) averaged at 0.67 for the period of 2000–2008. This suggests a dry nitrogen deposition load of 210.5 kg N/day to Suisun Marsh. Using the calculations of Geiser et al. (2010) as a benchmark, nitrogen deposition in Suisun Marsh (~2.5 kg N/ha/yr) appears to be well below the critical load above which nitrogen deposition can cause ecosystem harm.

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# 7. SOURCES OF MERCURY (THG/MEHG) TO SUISUN MARSH

Sources of total mercury (THg) and methylmercury (MeHg) to Suisun Marsh include atmospheric deposition, tributary inputs, loads from the Delta, and discharge from the municipal wastewater treatment plant (FSSD). Tidal action from the adjacent Suisun Bay and San Francisco Bay, as well as dynamic intra-Marsh conditions, can contribute total mercury or generate methylmercury within the marsh. Data and methods used to estimate mercury loads are described in detail in the Conceptual Model/Impairment Assessment Report (Tetra Tech 2013a). Despite recent downgrading of the load estimates, the Sacramento-San Joaquin Delta is the major source of inorganic mercury to San Francisco Bay and Suisun Marsh. Other more localized sources form a very small component of the total load (Figure 7-1).

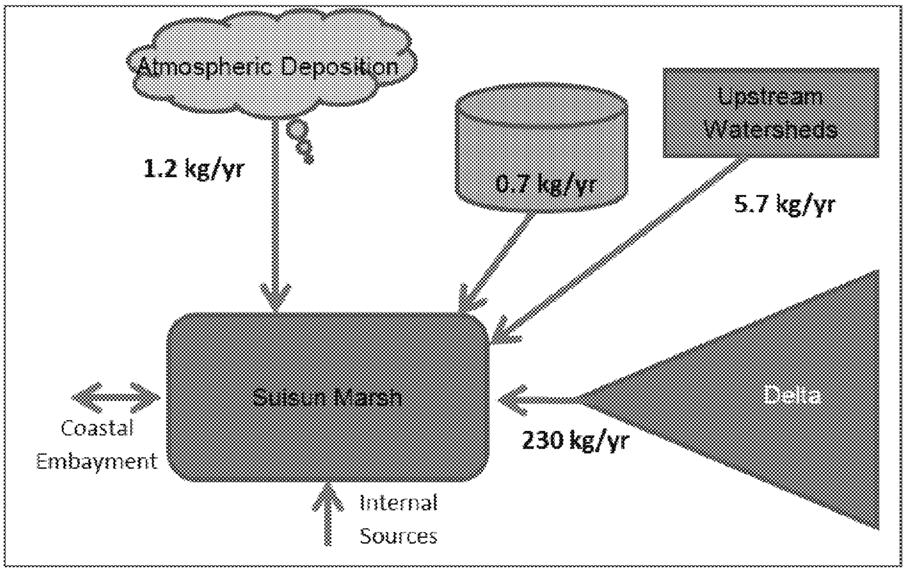


**Figure 7-1 Average mercury loads to Suisun Marsh area**

## 7.1. ATMOSPHERIC DEPOSITION

Atmospheric loads comprise mercury originating from global, regional and natural sources. Direct measurements of atmospheric deposition are sparse. Mercury concentrations in wet deposition (deposition via precipitation) were measured at three sites in the Bay–Delta region from April 2004–June 2006 (Gill 2008). Volume-weighted mercury concentrations observed at those sites were very similar, ranging from 3.7 to 4.2 ng/L. Estimated fluxes of wet deposition range from 1.5 μg/m$^2$/yr at Twitchell Island to 5.9 μg/m$^2$/yr at Pt. Reyes, depending on the precipitation amount.

Dry and wet seasonal deposition fluxes were measured at Moss Landing (Monterey County) and Woodland (Central Valley) (Table 7-1). Assuming wet deposition flux of 1.5 $\mu g/m^2/yr$ measured in close proximity to Suisun Marsh, and dry deposition flux of 1.25 $\mu g/m^2/yr$ (average of all estimates in Table 7-1), and the marsh surface area of 3.6 x $10^8$ $m^2$, direct dry and wet annual mercury deposition is approximately 1.2 kg/yr. This is in range with the previous assessment of 1.6 kg/yr (DWR 2007).

**Table 7-1**
**Comparison of wet and dry atmospheric deposition fluxes of mercury**

| Site | Period | Rainfall (cm) | [Hg] (ng/L) | Wet Deposition | | Dry Deposition | |
|---|---|---|---|---|---|---|---|
| | | | | $ng/m^2/month$ | $\mu g/m^2/yr$ | $ng/m^2/month$ | $\mu g/m^2/yr$ |
| Coast | Winter | 50 | 2.5 | 417 | 5.0 | 33 | 0.40 |
| Coast | Summer | 0.75 | 10 | 25 | 0.30 | 9.2 | 0.11 |
| Central Valley | Winter | 20 | 2.5 | 167 | 2.0 | 92 | 1.1 |
| Central Valley | Summer | 0.25 | 10 | 8 | 0.10 | 283 | 3.4 |

## 7.2. TRIBUTARY INPUTS

Stormwater loads of mercury from small tributaries to all of San Francisco Bay was estimated to vary from 200 to 400 kg/yr (Davis et al. 2001). Scaling down this estimate to the Fairfield–Suisun area, the mercury load in urban stormwater runoff was estimated to be 3.1 kg/yr.

The overall mercury load in non-urban stormwater runoff to San Francisco Bay is 25 kg/yr. Based on projected runoff volume from Davis et al. (2000b), non-urban runoff from the Fairfield–Suisun area is estimated to contribute 1.9 kg/yr. When the size of drainage area is considered, non-urban runoff of mercury from Fairfield–Suisun is 2.6 kg/yr. The combined urban and non-urban stormwater load, therefore, can vary from 5 to 5.7 kg/yr.

## 7.3. LOADS FROM THE DELTA

Mercury enters the Delta in the form of contaminated sediment and contaminated runoff. The origin of much of this mercury is historical mining activities in the Coast Range and the Sierra Nevada, which used elemental mercury for gold and silver extraction (DWR 2007). Hydraulic mining for gold, which began in the 1850s and was banned in 1884, was responsible for the widespread distribution of mercury-contaminated sediment throughout the estuary including Suisun Marsh. Recent studies suggest that about 350–750 kg/yr of mercury is still being transported into the Delta from the Coast Range and the Sierra Nevada. Louie et al. (2008) estimated that more than 70% of the load entering the Delta is exported to San Francisco Bay. Average annual export of total mercury to Suisun Bay at Mallard Island varies from 198 kg/year to 361 kg/yr depending on the mix of wet and dry years used in the evaluation period that spanned from 1984 through 2006. For the most recent decade of data (1995-2006), the annual average load is estimated to be 230 kg/yr (~630 g/day). This estimate is somewhat lower than the previously projected export of 1050 g/day (~ 383 kg/yr) or the Bay Mercury TMDL estimate of 440 kg/yr.

## 7.4. Wastewater Treatment Plant

FSSD is an advanced secondary treatment wastewater facility discharging treated wastewater effluent to Boynton Slough. FSSD's mercury load from 2012-2015 varied from 0.022 to 0.030 kg/yr (average 0.026 kg/yr), which is diminutive compared to other sources to the marsh. The Bay Mercury TMDL allocated 11 kg/yr of mercury for all municipal wastewater facilities discharging to the Bay, including FSSD. The combined average municipal wastewater load to the Bay for the past five years has been about 3.1 kg/yr, less than a third of the TMDL limit. This load reduction has been achieved through implementation of Bay-wide pollution prevention actions, improvements in solids removal, and intensive mercury recycling efforts.

## 7.5. Interface with San Francisco Bay

Mercury strongly adsorbs to sediment particles, so inorganic mercury historically entered Suisun Marsh channels from Suisun Bay through tidal transport, creating legacy total mercury sediment concentrations similar in magnitude to those in upper-level San Francisco Bay sediments. Today, mercury contamination and distribution throughout the Bay-Delta estuary is relatively uniform, indicating that the net mercury load to Suisun Marsh due to erosion of bottom sediments in San Francisco Bay is likely to be small, especially when compared to the riverine fluxes. The extent of these loads has not been precisely quantified but they are already captured in the TMDL mercury budget for San Francisco Bay.

The inventory of mercury in San Francisco Bay bottom sediments remains high (approximately 60,000 kg) but is expected to slowly decrease as new releases of mercury get smaller and mercury is lost via hydrologic transport to the Pacific Ocean (Yee et al. 2011). Over the last decade, the average mercury concentrations in sediments have been the lowest in Suisun Bay (~0.17 ppm), while concentrations in San Pablo Bay have been slightly higher at 0.27 ppm (SFEI 2015). These concentrations are similar to mercury found in surficial sediments (top 1 cm) in Suisun Marsh, which varied from 0.2 to 0.33 ppm (Slotton et al. 2002).

## 7.6. Managed Wetlands

Managed wetlands, and to a lesser degree tidal wetlands, can also generate MeHg from total mercury, when anaerobic conditions exist in the water and sediment. MeHg bioaccumulates in the food web and is thus more toxic than total mercury, which is not bioavailable. The MeHg fluxes measured at an experimental study site on Grizzly Island varied from 0.007 to 0.068 g/day. When scaled up for the 52,000 acres of managed wetlands in Suisun Marsh, this translates to 0.122 to 0.46 g/day of MeHg being exported to Montezuma Slough and Grizzly Bay (Stephenson et al. 2010). These loads, however, are relatively small when compared to the load of MeHg carried by tributaries to the Delta of 16.6 g/day, and they are likely to vary significantly depending on the water management system at individual wetlands. Some data from Suisun Marsh also suggests that the MeHg flux is not unidirectional. As we learn more about mercury transformations and MeHg releases under specific conditions in Suisun Marsh, the load and flux assessments may change. However, the high temporal and spatial variability associated with the measured loads are likely to remain regardless of the amount of data being collected, because such variability is inherent in a biologically and hydrologically complex environment such as Suisun Marsh.

# 8. LINKAGE ANALYSIS: DISSOLVED OXYGEN AND ORGANIC CARBON

## 8.1. MODELING LINKAGES BETWEEN ORGANIC CARBON, NUTRIENTS AND LOW DO

Understanding the link between discharges from managed wetlands and changes in water quality in adjacent sloughs is essential to achieving the proposed site-specific objectives and implementing the load allocations in the TMDL. It allows for determination of the relative contribution of managed wetlands to dissolved oxygen sags, and for evaluation and testing of the effectiveness of various management options to improve water quality. Tetra Tech used the numeric hydraulic model HEC-RAS to simulate linkages between organic carbon loads from managed wetlands and DO in Suisun Marsh sloughs. The model was run for two example sloughs that experienced frequent low DO, Boynton and Peytonia sloughs, which were also continuously monitored by Siegel et al. (2011) during 2007–2008, and two other sloughs, Goodyear and Denverton sloughs, for which the continuous DO data from 2012–2013 were available (Figure 8-1). Details of model setup and the results are presented in Appendix C.

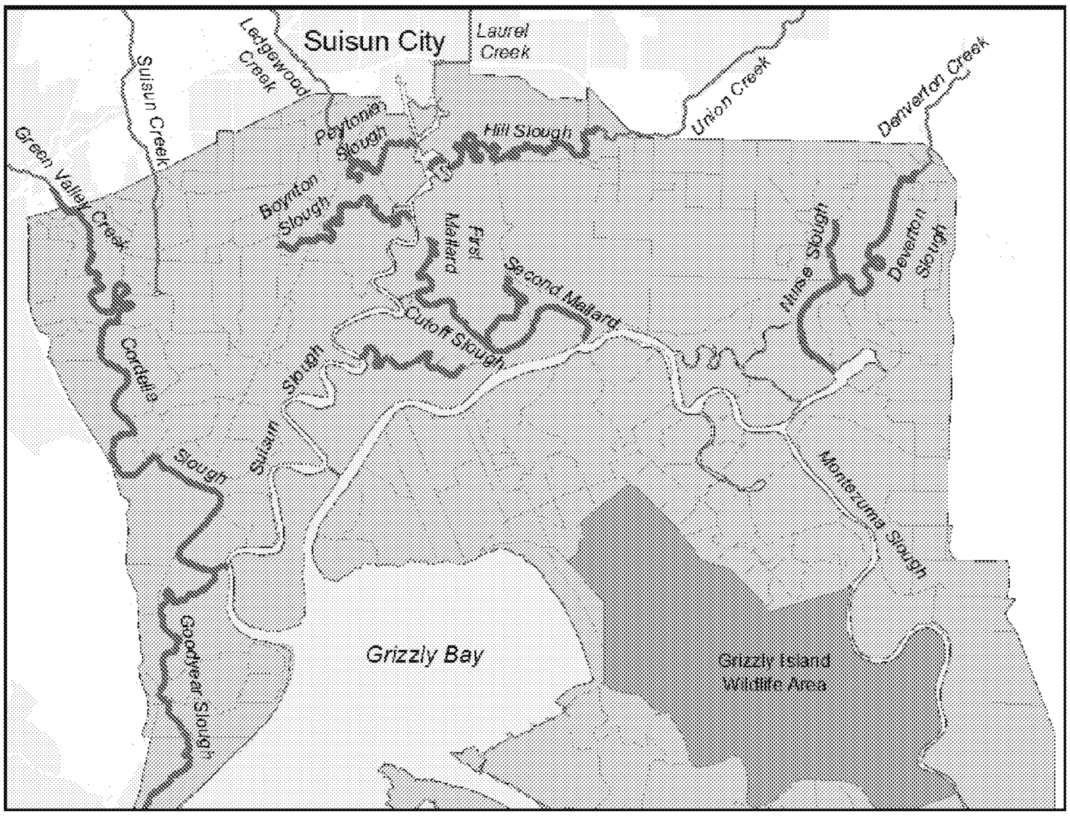


**Figure 8-1** **Map of major sloughs in Suisun Marsh. Among these, Boynton Slough, Peytonia Slough, Goodyear Slough, and Denverton Slough are modeled**

The application of HEC-RAS provided a way to explain a dynamic linkage between DO, BOD, organic carbon, and nutrient levels. By using the model to match the observed DO levels at specific locations within Suisun Marsh, the relative contribution of different sources to the condition of concern, specifically the DO sags, can be identified and tested. The model considers each slough to be a one-dimensional channel, with tidal flows exchanging through downstream end of the slough. Upstream freshwater flows and flows from managed wetlands are considered as inputs along the channel length. Within the slough, the model describes how DO uptake occurs as a result of biological oxygen demand (BOD) by different sources as well as DO demand generated from organic carbon decomposition. Organic carbon can enter the slough as inflow from managed wetlands or may be generated internally through primary production, which is related to the levels of nutrients present. The model also simulates the effects of chemical processes like reaeration, photosynthesis and respiration, oxidation of ammonia and nitrite, and sediment oxygen demand.

In addition to simulation of managed wetland discharges, the modeling also considered the impact of decomposition of naturally-occurring organic carbon from background sources on lowering DO concentrations. Comparison of DO in the low DO-impacted sloughs (Boynton, Peytonia and Goodyear Sloughs) to the DO levels in First and Second Mallard Slough, which are minimally affected by managed wetlands, showed that the DO sags in the impacted sloughs were more severe than they would have been under the natural load of organic carbon decomposition within these environments. The additional decline in DO reflects the increased oxygen demand that the organic-rich seasonal discharges from the managed wetlands generate.

DO concentrations from the minimally impacted sites (First and Second Mallard Sloughs) also provide an opportunity to examine the level of variability in DO concentrations under unimpaired conditions. The model-simulated sources and sinks of DO in the sloughs suggest that processes that affect DO concentrations including reaeration, oxidation of BOD, photosynthesis and respiration, are generally comparable in magnitude. Conversely, oxygen consuming processes such as oxidation of ammonia, nitrite, and sediment oxygen demand seem to occur at lower rates, which suggest that nutrients are not the key factor in lowering DO in the marsh sloughs (Figure 8-2).

For each slough, a prescribed schedule of discharges from managed wetlands was used to match the observed DO sags. Managed wetland discharges were assumed to have lowest observed DO concentrations of 0.1–0.7 mg/L and high DOC concentrations (40–70 mg/L) as reported in Siegel et al. (2011). The modeled sloughs typically experienced 3 to 4 low DO events of different magnitude during fall and 1 to 2 low DO events during spring, corresponding to discharges from managed wetlands.

## 8.2. Impact of Discharge Timing and Volume on DO

The modeling of temporal DO variations in four different sloughs under current conditions provided a basis for evaluating anticipated implementation by modifying conditions within the sloughs, such as managed wetland discharges, upstream freshwater inflows, and wastewater treatment plant flows, as well as nutrient, BOD, and DO levels in any of the inflows. These changes form the basis of the strategies proposed to achieve water quality targets in Suisun Marsh (see discussion on implementation in Section 12). Two model scenarios were tested to achieve the hypothetical DO concentration of 5 mg/L on continuous basis:

1. Reduction of managed wetland discharge volumes until achieving continuous exposure of 5 mg/L in the sloughs.
2. Discharge over a longer period without reduction in load, with the maximum allowable continuous daily discharge from managed wetlands calibrated to attain the DO exposure of 5 mg/L.

Simulations were performed separately for each slough with available data, because the hydromorphology of individual sloughs and the contributing managed wetlands influence the DO response. For both model scenarios considered, DO levels in the managed wetland discharges were conservatively assumed to be at the lowest levels, and the focus was on modifying the timing and volume of the discharge to achieve 5 mg/L DO all the time. The HEC-RAS simulations demonstrated that changes to water management at the duck club properties, and specifically reductions in discharge by 40 to 60%, could result in a significant improvement in DO conditions in the receiving slough. Similar improvements could be accomplished by allowing for discharge to occur over longer periods of time. This confirms implementation actions that improve water management, such as staggering discharges in individual sloughs, redirecting discharges to larger sloughs when possible, and coordinated release of FSSD high DO-treated effluent, provide the best opportunity to improve DO and is the most efficient use of the available resources.

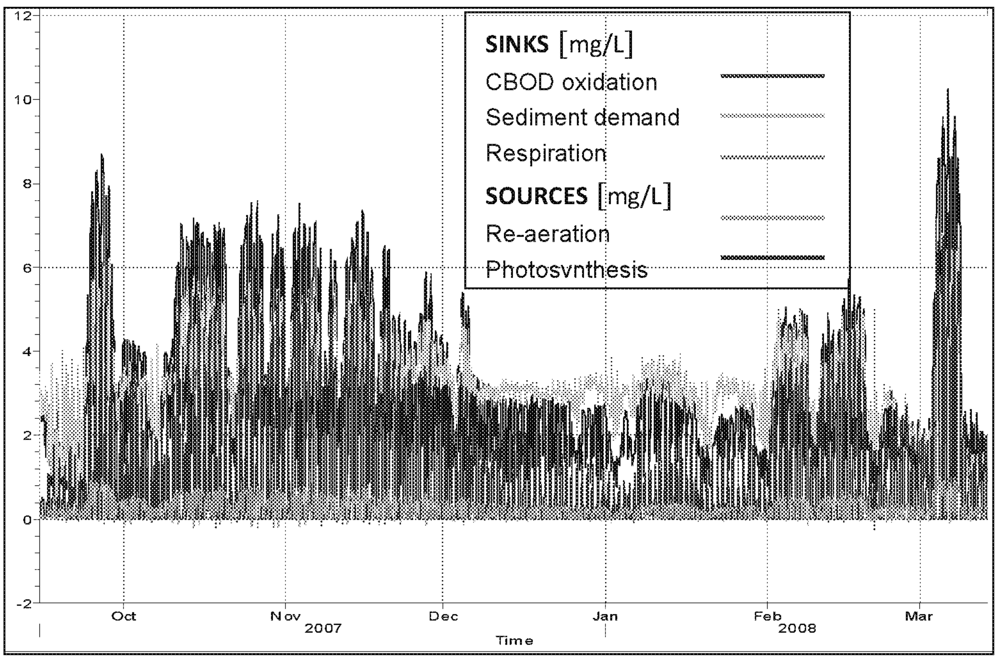


**Figure 8-2 Modeled sources and sinks of DO in Boynton Slough**

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# 9. TMDL ALLOCATIONS AND MARGIN OF SAFETY: DISSOLVED OXYGEN

## 9.1. DISSOLVED OXYGEN TMDL AND ALLOCATIONS

U.S. EPA's protocol for developing TMDLs defines a total maximum daily load as the allowable loadings of a specific pollutant that a water body can receive without exceeding water quality standards. For most pollutants, TMDLs are expressed as mass loadings (e.g., kilograms per year). EPA Regulations (40 CFR §130.2(i)) provide that TMDLs do not need to be expressed as mass per unit time, but may be expressed in terms of an "other appropriate measure." Dissolved oxygen concentrations are an important indicator of wetland habitat health because all aquatic organisms require some minimum level of DO to survive and prosper. Therefore, DO concentration is a relevant criterion for assessing the impact of a discharge on receiving waters, the quality of the affected receiving waters, and for the ability of the water body to support aquatic life beneficial uses.

The site-specific DO objectives derived using the U.S. EPA recommended methodology are tailored to be protective of all sensitive aquatic life beneficial uses in Suisun Marsh (Section 4 this Staff Report). The proposed TMDL is established to attain and maintain these DO objectives. The implementation actions for the TMDL are focused on the western part of Suisun Marsh bordered to the east by Suisun Slough (Figure 9-1). As discussed in Section 3, the western part of Suisun Marsh is of the most concern due to a high density of managed wetlands and limited mixing in small dead-end sloughs. That area had also experienced the most severe low DO events and fish kills in the past.

The TMDL requires the DO concentrations in the sloughs to be $\geq$ 3.8 mg/L, which ensures protection of juvenile and adult survival, and $\geq$ 5 mg/L, which protects against adverse growth effects based on a continuous exposure. Expressing the TMDL as DO concentrations in the receiving waters equal to the proposed water quality objectives provides a direct measurable target for the sources to monitor for compliance. Table 9-1 presents concentration-based load and wasteload allocations proposed for Suisun Marsh. The attainment of these allocations will ensure that conditions in the sloughs support the most sensitive aquatic life beneficial uses present. These allocations will apply year-round. All permittees and/or entities that contribute to low DO conditions are collectively responsible for meeting these allocations. Water quality monitoring data collected at selected sloughs will be used to demonstrate achievement of the allocations.

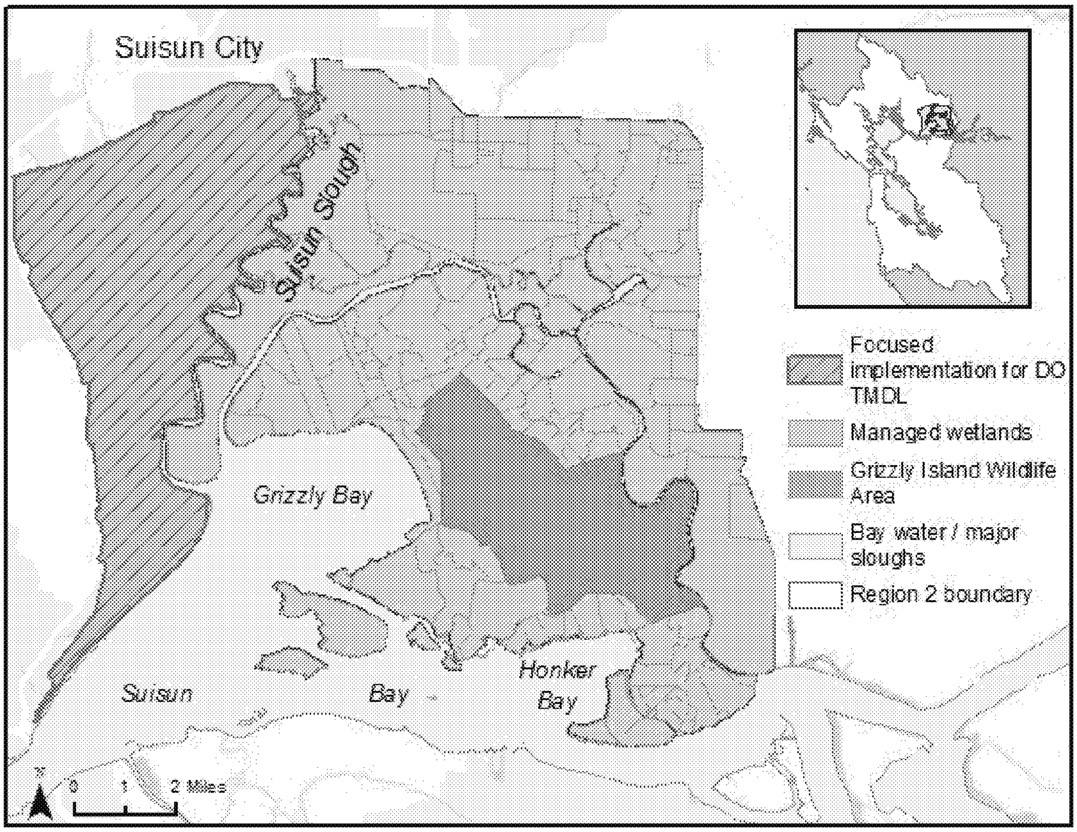


**Figure 9-1 Low DO/ organic enrichment TMDL for Suisun Marsh**

**Table 9-1**
**Wasteload and load allocations for Suisun Marsh DO TMDL**

| Source | Allocations |
|---|---|
| | **Wasteload Allocations** |
| Fairfield-Suisun Sewer District (FSSD) NPDES Permit No. CA0038024 | Discharge shall not cause DO concentrations in receiving waters to decrease below 5.0 mg/L June 1-November 15 and 7.0 mg/L during all other times of the year [a, b] |
| Municipal stormwater runoff in tributaries draining to Suisun Marsh NPDES Permit No. CAS612008 | DO concentration in local tributaries draining urban areas and discharging to Suisun Marsh shall be ≥ 5 mg/L [b] |
| | **Load Allocations** |
| Managed wetlands | Discharges from managed wetlands shall not cause the DO concentrations in the sloughs to decrease below 3.8 mg/L [c] and 5 mg/L [b] |

a As specified in the NPDES permit for this facility
b Expressed as 30-day running average
c Expressed as 1-day average



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### 9.2. Margin of Safety

Since the allocations in this TMDL are identical to the proposed water quality objectives the margin of safety for this TMDL is implicitly included. The water quality objectives take uncertainties into account, reflect conservative assumptions, and consider acceptable risks. These DO objectives were developed to protect sensitive beneficial uses, and, compliance with the objectives is expected to ensure that fish, invertebrates, and other aquatic organisms can survive and prosper in Suisun Marsh habitats.

### 9.3. Seasonal Variations and Critical Conditions

In developing the TMDL we considered water quality and fish data spanning more than two decades, and including the worst four consecutive dry years (2011-2015) since rainfall recordkeeping began in 1895. DO concentrations in Suisun Marsh sloughs, and especially in the western part of the marsh, tend to be lowest in the fall (October-November) when discharges from the managed wetlands combined with low freshwater inflows and limited tidal mixing result in overall decline in water quality. Meeting the DO targets under the critical flow and temperature conditions in the fall will ensure that the water quality objectives and the TMDL will be achieved at all times throughout the year.

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# 10. LINKAGE ANALYSIS: MERCURY

## 10.1. MERCURY METHYLATION IN SUISUN MARSH

As discussed in sections 3 and 5, methylmercury is more bioavailable, and consequently more toxic, to humans and aquatic life than inorganic mercury. Accordingly, limiting conversion of inorganic mercury to methylmercury (MeHg) is as important in preventing bioaccumulation as limiting discharges of mercury. Marshes and subtidal waters with low oxygen content provide conditions favoring MeHg production (e.g. Davis et al. 2012, Heim, 2003; Hurley et al. 1995, Marvin-DiPasquale et al. 2003; Slotton et al. 2002). A conceptual model of MeHg production in Suisun Marsh is shown in Figure 10-1. Although conditions promoting mercury transformations often occur naturally in marshes and wetlands, managed wetlands were found to have higher MeHg concentrations than other areas in Suisun Marsh. While MeHg production is not well understood, long cycles of wetting and drying, high organic carbon concentrations and low DO are known factors that promote formation of reactive Hg and increase methylation potential. According to Siegel et al. (2011), tidal marsh that receives daily tidal exchange generally does not provide the necessary inundation regime to substantially increase methylation production. Kelly et al. (1997) identified three changes in environmental conditions that stimulate mercury methylation, and are linked to the operations of managed wetlands (duck clubs) in Suisun Marsh. These are: 1) sudden death of vegetation available for decomposition and supplying a large amount of organic carbon, 2) high decomposition rate leading to an increase in anaerobic habitat, and 3) elevated temperatures often present in shallow, slow-flowing back-end sloughs. Therefore, making changes to water management in the managed wetlands and restoring portions of those wetlands to tidal action would likely contribute to lower methylation. Moreover, it would reduce incidents of dissolved oxygen depletion, prevent fish kills, and subsequently diminish MeHg impacts on aquatic life, wildlife, and humans.

Key processes affecting formation and loss of reactive inorganic mercury (Hg(II)), methylation, and demethylation in the marsh environment are summarized below. A detailed assessment of mercury cycling in Suisun Marsh, available data and potential ramifications for transformations of managed wetlands to tidal wetlands are discussed in Tetra Tech (2013a, b).

### *10.1.1 Formation and Loss of Reactive Hg(II)*

Methylmercury concentrations in water and sediments are affected by the available pool of reactive Hg(II) ready for methylation. Different processes affect the formation and loss of reactive Hg(II) available for methylation and different forms of mercury are associated with different sources, with some being more bioavailable for methylation than the others. For example, Hg-chlorides or Hg sulfates are more bioavailable than Hg(0) and HgS. The formation of reactive Hg(II) includes dissolution of HgS by organic acids or complexation with organic carbon. This process is affected by sediment and water properties such as organic carbon concentrations, redox potential (Fe, S), pH, dissolved oxygen, salinity, and nutrients. In particular, organic carbon has been found to be important in dissolution of HgS to form reactive Hg(II).

### 10.1.2 Methylation and Demethylation

Alpers et al. (2008) hypothesized that the net formation of MeHg in sediment and/or water is a result of competing microbiological and abiotic reactions. Although microbiologically mediated processes tend to dominate in natural environments, the abiotic processes were also found to contribute to MeHg formation and degradation.

Methylation of Hg is carried out mainly by anaerobic sulfate- and iron-reducing bacteria at the oxic/anoxic interface in soils/sediments where these bacteria are present. Therefore, sediment and water properties that affect activity of these bacteria are important to controlling methylation. High organic carbon levels can fuel microbial activity. Reduction of sulfate and iron requires anoxic conditions, so in most situations low dissolved oxygen promotes the methylation process.

Demethylation can be carried out both biotically and abiotically. An example of abotic demethylation is photodemethylation, in which ultraviolet radiation and visible sunlight cause methylmercury to convert to inorganic mercury. Biotic demethylation can be through both oxidative pathway (to form $CO_2$) or through reductive pathway (by uptake of $CH_4$). In both cases, maintaining high levels of DO may reduce methylation potential.

## 10.2. Environmental Factors Contributing to High Methylation Rates in Suisun Marsh

### 10.2.1 Flooding and Drying in Managed Wetlands

Managed wetlands have higher levels of methylmercury than other types of wetland habitat, which is believed to be a product of their wetting and drying cycles. These cycles promote the formation of the reactive oxidized ionic form of mercury ($Hg(II)_R$), which methylates more easily than other forms of mercury (Alpers et al. 2008), and provide extensive oxic/anoxic surfaces for methylation in the sediment-water interface. More specifically, the drying periods replenish oxygen and lead to subsequent oxidation of Hg(0) to form reactive Hg(II); the drying also accelerates decomposition of marsh litter and conversion of reduced forms (e.g. $Hg^0$, sulfide, $Fe^{2+}$) to oxidized forms (e.g., sulfate, $Fe^{3+}$) (Yee et al. 2008). During the wetting periods, anoxic conditions favorable to iron- and sulfate-reducing bacteria persist in sediments, which enhances methylmercury production. Such conditions intensify natural biogeochemical processes leading to mercury methylation. For example, the low DO concentrations when the wetlands are flooded can affect the oxidation-reduction state of mercury and other elements that are commonly important in mercury cycling such as sulfur, iron, and, to a lesser extent, manganese.

In contrast, low levels of MeHg were found in open water Bay-Delta habitats, while moderate concentrations were found in habitats that flood frequently and do not fully dry, such as tidal marsh. Relatively high levels of MeHg were found in habitats that flood less frequently and are allowed to completely dry (e.g. high tidal marsh) before returning to anoxic conditions (Marvin-DiPasquale and Cox 2007). However, MeHg levels in high tidal marsh are still lower than levels in managed wetlands. (Heim et al. (2007).

The role of managed wetlands in production of methylmercury was illustrated recently in a study at managed Wetlands 112 and 123 (Bachand et al. 2010). At Wetland 123, drain events have consistently higher unfiltered MeHg concentrations (3–7 times) and higher filtered MeHg (3–20 times). Heim et al. (2007) found MeHg concentrations higher in the managed wetland interiors than on the edges, and higher concentrations in marshes than in open channel waters.

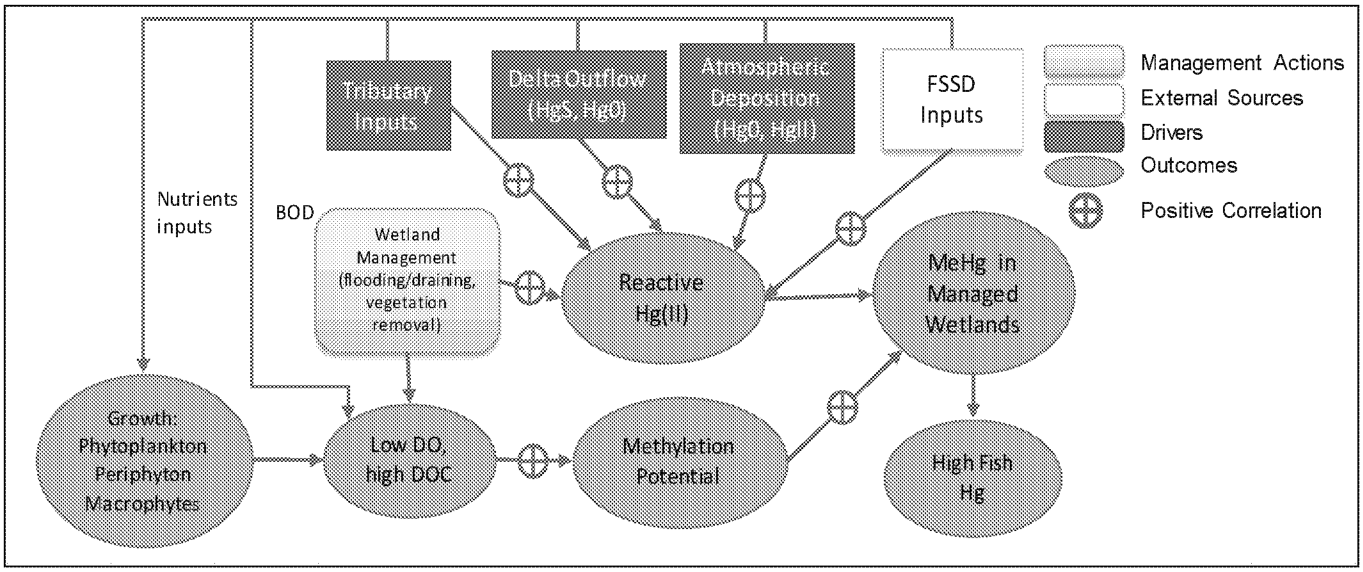


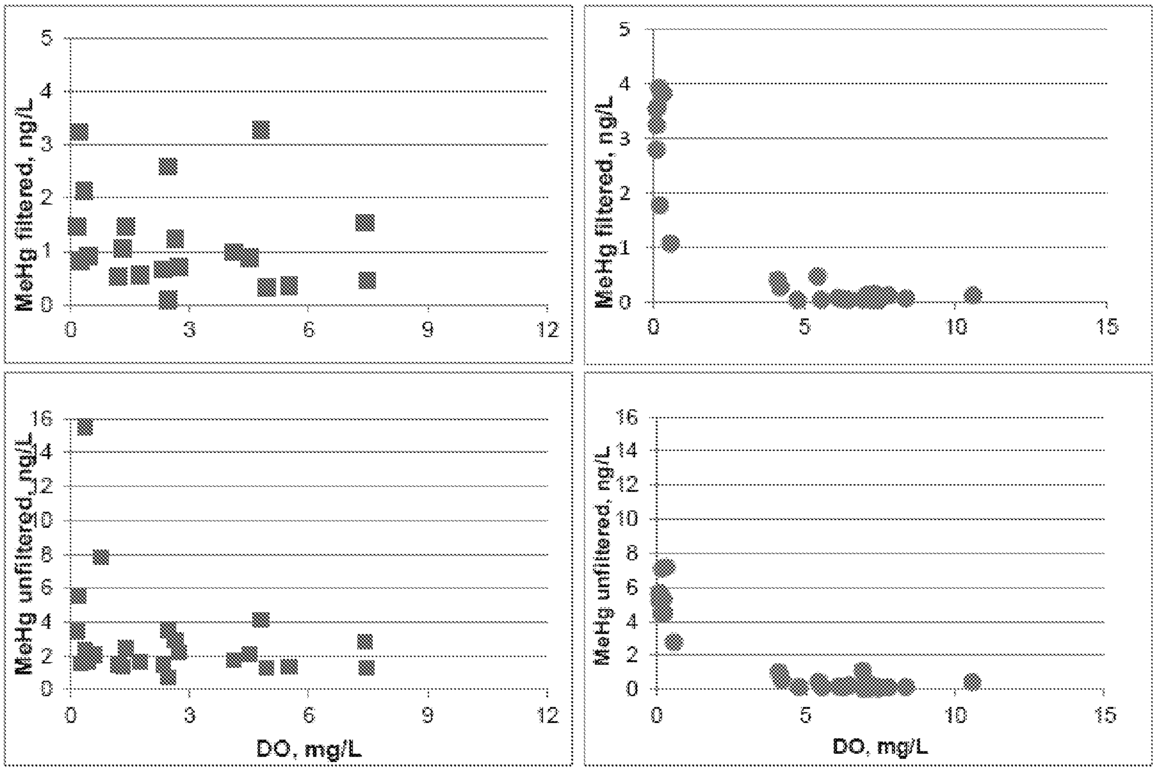

**Figure 10-1 Cause-and-effect relationships of mercury in Suisun Marsh**

### *10.2.2 High Dissolved Organic Carbon*

High organic carbon in managed wetlands also contributes to high mercury methylation potential in Suisun Marsh because elevated organic carbon fuels microbial activities that are responsible for methylation.. Managed wetlands generate high levels of organic carbon because they support different types of primary production: 1) macrophytes, 2) benthic algae and 3) phytoplankton, and have soils rich in organic matter. During the recent study of Wetlands 112 and 123, Bachand et al. observed both elevated dissolved organic carbon and methylmercury concentrations within a few weeks of flooding. (Bachand et al. 2010).

## 10.3. DO AND MEHG PRODUCTION

Because of the abundance of inorganic mercury in the sediments and waters flowing into and out of Suisun Marsh, control of inorganic mercury sources beyond what is required under the Mercury TMDL is not feasible or practical. However, the clear linkage between organic carbon cycling and low DO concentrations provides a meaningful path to create conditions that do not increase or exacerbate MeHg concentrations. Specifically, as shown in Figure 10-2, both filtered and unfiltered MeHg concentrations in the managed wetlands are lower when water column DO concentrations are higher than 4 mg/L. In contrast, when near-anoxic conditions are present (< 2 mg/L), MeHg concentrations are two to four times higher than at DO levels above 4 mg/L, which can result in substantial loading of MeHg from the managed wetlands to the sloughs. Accordingly, implementation of actions to increase DO and limit anoxic conditions, are likely to simultaneously reduce MeHg levels. Thus, approaches to increase the DO levels in the slough waters to protect aquatic organisms are also directly related to potential improvement in Hg levels.




*Data re-plotted from Siegel et al. 2011; left panel: interior samples, right panel: exterior samples*

**Figure 10-2 MeHg concentrations versus DO in filtered and unfiltered samples from managed wetlands**

The large-scale conversion of managed wetlands in Suisun Marsh and the Delta to tidal marsh, planned as mitigation for the California Water Fix and other large projects, is expected to increase tidal flows throughout Marsh sloughs over the course of the next few decades. Increased tidal flows are expected to improve DO and reduce sulfide concentrations, which in turn is expected to reduce methylation potential. MeHg concentrations in tidal wetlands are up to an order of magnitude lower than those reported from diked wetlands managed for agriculture and/or waterfowl habitat (Siegel et al. 2011); accordingly, the restoration of tidal flows and circulation is expected to reduce MeHg significantly. Some level of MeHg production will still persist, as even tidal wetlands possess properties supporting methylation (Tetra Tech 2013b). However, shorter wetting and drying cycles and higher volume of water exchange (twice daily) are expected to make the tidal marshes less conducive to methylmercury production.

# 11. TMDL ALLOCATIONS AND MARGIN OF SAFETY: MERCURY

## 11.1. APPLICABILITY OF THE BAY MERCURY TMDL AND ALLOCATIONS

The San Francisco Bay TMDL, adopted in 2006, identifies the sources of mercury, prescribes the maximum load that the Bay can assimilate, and determines the load and wasteload allocations for all sources, including point and non-point sources contributing mercury to Suisun Marsh. This load allocation currently stands at 700 kg/yr expressed as total mercury (SFBRWQCB 2006). Significant load reductions are expected to be achieved through its implementation plan, which includes control actions for refineries, wastewater treatment plants, stormwater management agencies, and Central Valley watershed. These allocations and implementation plan already aim at protection of wildlife and human health related to consuming fish in San Francisco Estuary; accordingly it is appropriate to extend the allocations and implement the mercury objectives in Suisun Marsh, too.

Control actions and regulatory requirements to reduce mercury in the estuary are being implemented through the San Francisco Bay and Delta Mercury TMDLs. The Bay TMDL requires municipalities to reduce mercury loading in urban stormwater runoff by 80 kg/yr from the estimated 160 kg/yr. This is being accomplished by introducing numerous control measures such as enhanced mercury-containing light bulb and device recycling, improved operation and maintenance of stormwater infrastructure, and identification and cleanup of contaminated sites. The TMDL anticipates a 110 kg/yr reduction as a result of control measures mandated by regulatory efforts in the Central Valley to reduce the mercury loads associated with historic mercury and gold mining in the watersheds of the Sierra Nevada foothills and the Coast Range drained by the Sacramento and San Joaquin Rivers. The wastewater municipal facilities Bay-wide must also reduce their loads of Hg by about 40% to achieve an approximately 10 kg/yr reduction. The Fairfield Suisun wastewater treatment plant is among the municipal dischargers named by the Bay TMDL with assigned wasteload allocations. The average municipal wastewater load for the past five years has been about 3.1 kg/yr, less than half the final TMDL limit of 11 kg/yr.

The Bay Mercury TMDL also recognizes that wetlands may contribute substantially to methylmercury production and biological exposure to mercury within the Bay. Implementation tasks related to the wetlands focus on managing the existing wetlands and ensuring that newly constructed wetlands are designed to minimize methylmercury production and subsequent transfer to the food web. Extending the TMDL's allocations and objectives to Suisun Marsh will help ensure that tidal restoration in Suisun Marsh will not result in net increase in mercury load to the Bay.